APPENDIX A

DECLARATION

I, Hisato NODA, c/o Fukami Patent Office, Nakanoshima Central Tower, 22nd Floor, 2-7, Nakanoshima 2-chome, Kita-ku, Osaka-shi, Osaka, Japan, declare:

that I know well both the Japanese and English languages;

that to the best of my knowledge and belief the English translation attached hereto is a true and correct translation of Japanese Patent Application No. 2003-053748, filed on February 28, 2003;

that all statements made of my own knowledge are true;

that all statements made on information and belief are believed to be true; and

that the statements are made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under 18 USC 1001.

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[List of the Accompanying Documents]

[Document]	Specification	1
[Document]	Drawings	1
[Document]	Abstract	1

[Document Name]   Specification

[Title of the Invention]   A Support Structure in a Transmission, Method of Manufacturing the Same, and Tapered Roller Bearing

[Scope of Claims for Patent]

[Claim 1]   A support structure having a rolling bearing rotatably supporting an input shaft, an output shaft or toothed wheels in a transmission capable of changing a rotational speed of said output shaft relative to a rotational speed of said input shaft by means of mesh of said toothed wheels, said rolling bearing including an inner member, an outer member and a rolling element, wherein at least any one of said members and element has a carbonitrided layer and an austenite grain with a grain size number falling within a range exceeding 10.

[Claim 2]   A support structure having a rolling bearing rotatably supporting an input shaft, an output shaft or toothed wheels in a transmission capable of changing a rotational speed of said output shaft relative to a rotational speed of said input shaft by means of mesh of said toothed wheels, said rolling bearing including an inner member, an outer member and a rolling element, wherein at least any one of said members and element has a carbonitrided layer and a fracture stress value of no less than 2650 MPa.

[Claim 3]   A support structure having a rolling bearing rotatably supporting an input shaft, an output shaft or toothed wheels in a transmission capable of changing a rotational speed of said output shaft relative to a rotational speed of said input shaft by means of mesh of said toothed wheels, said rolling bearing including an inner member, an outer member and a rolling element, wherein at least any one of said members and element has a carbonitrided layer and a hydrogen content of at most 0.5 ppm.

[Claim 4]   The support structure according to any of claims 1-3, wherein said rolling bearing is a tapered roller bearing.

[Claim 5]   The support structure according to any of claims 1-3, wherein said rolling bearing is a needle roller bearing.

[Claim 6]   The support structure according to any of claims 1-3, wherein said

rolling bearing is a ball bearing.

[Claim 7]   A method of manufacturing a support structure having a rolling bearing rotatably supporting an input shaft, an output shaft or toothed wheels in a transmission capable of changing a rotational speed of said output shaft relative to a rotational speed of said input shaft by means of mesh of said toothed wheels, the method comprising the step of forming at least one of an inner member, an outer member and a rolling element of said rolling bearing, wherein the step of forming includes the step of carbonitriding steel for a component of said bearing at a temperature higher than an A_1 transformation point and then cooling the steel to a temperature lower than the A_1 transformation point and subsequently reheating the steel to a range of temperature of no less than the A_1 transformation point and less than said temperature applied to carbonitride the steel, and quenching the steel.

[Claim 8]   The method according to claim 7, wherein said range of temperature at which the quenching begins is 790°C to 830°C.

[Claim 9]   A tapered roller bearing having an inner ring, an outer ring, and a tapered roller, wherein at least any one of said inner ring, said outer ring and said tapered roller has a carbonitrided layer and an austenite grain with a grain size number falling within a range exceeding 10.

[Detailed Description of the Invention]

[Technical Field to Which the Invention Belongs]

The present invention relates to a support structure in a transmission that has a long rolling contact fatigue life, an increased anti-crack strength, or a reduced secular variation in dimension, and to a method of manufacturing the same and a tapered roller bearing.

[Conventional Art]

To increase a bearing's components in life against rolling contact fatigue, a thermal treatment is performed.   Specifically, for example, in quenching the components they are heated in an ambient RX gas with ammonium gas further

introduced therein to carbo-nitride their surface layer portion, for example as disclosed in Japanese Patent Laying-Open Nos. 8-4774 and 11-101247. This carbonitriding process can harden the surface layer portion and generate retained austenite in a microstructure to provide increased rolling contact fatigue life.

[Patent Document 1]   Japanese Patent Laying-Open No. 8-4774

[Patent Document 2]   Japanese Patent Laying-Open No. 11-101247

[Problems to be Solved by the Invention]

The above-mentioned carbonitriding process is a process to diffuse carbon and nitrogen. This requires a high temperature maintained for a long period of time. As such, for example a coarsened structure results and increased anti-crack strength is hardly obtained. Furthermore, as more austenite is retained, secular dimensional variation rate increases, which is also a problem in this carbonitriding process.

Against rolling fatigue, an increased life can be ensured, an enhanced anti-crack strength provided and an increased secular dimensional variation avoided by relying on designing a steel alloy to provide an adjusted composition. Relying on designing the alloy, however, increases source material cost disadvantageously.

Future bearings in a transmission will be used in environments exerting large loads at high temperatures. In addition, they will be required to be employed in a downsized transmission. Therefore, the bearings will be required to be operable under larger loads at higher temperatures than conventional. As such, there is a demand for a bearing having large strength, long life against rolling contact fatigue, and large anti-crack strength and dimensional stability.

It is an object of the present invention to provide a support structure in a transmission that has an increased anti-crack strength, an enhanced dimensional stability, and a long rolling contact fatigue life, and a method of manufacturing the same and a tapered roller bearing.

[Means for Solving the Problems]

The present invention provides a support structure in a transmission capable of

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changing a rotational speed of an output shaft relative to a rotational speed of an input shaft by means of mesh of toothed wheels. The support structure has a rolling bearing supporting the input shaft, the output shaft or the toothed wheels rotatably. The rolling bearing includes an inner member, an outer member and a rolling element, and at least any one of the members and element has a carbonitrided layer and an austenite grain with a grain size number falling within a range exceeding 10.

In the support structure in the transmission according to the present invention, at least one of an inner member, an outer member and a rolling element contains austenite grains having a small size allowing significantly increased anti-crack strength, dimensional stability and rolling contact fatigue life. With the austenite grain size number of 10 or less, any remarkable improvement of the fatigue life is impossible and thus the grain size number is greater than 10, and preferably 11 or greater. Although further finer austenite grains are desirable, the grain size number exceeding 13 is usually difficult to achieve. Note that an austenite grain of the inner member, outer member and rolling element of the support structure in the transmission does not vary whether it may be in a surface layer portion significantly affected as it is carbo-nitrided or a portion inner than the surface layer portion. As such, the surface layer portion and the inner portion will be set as positions serving as subjects of the aforementioned grain number range.

The present invention provides another support structure in a transmission capable of changing a rotational speed of an output shaft relative to a rotational speed of an input shaft by means of mesh of toothed wheels. The support structure has a rolling bearing supporting the input shaft, the output shaft or the toothed wheels rotatably. The rolling bearing includes an inner member, an outer member and a rolling element, and at least any one of the members and element has a carbonitrided layer and a fracture stress value of no less than 2650 MPa.

The present inventors have found that steel that is carbo-nitrided at a temperature exceeding an A_1 transformation point and then cooled to a temperature of

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less than the A_1 transformation point, and subsequently reheated to a range of temperature higher than the A_1 transformation point and is quenched, can be provided with a carbo-nitrided layer allowing the steel to provide a fracture stress value of no less than 2650 MPa, which has conventionally not been achieved. A support structure in a transmission superior in fracture stress to conventional and thereby larger in strength can thus be obtained.

The present invention provides still another support structure in a transmission capable of changing a rotational speed of an output shaft relative to a rotational speed of an input shaft by means of mesh of toothed wheels. The support structure has a rolling bearing supporting the input shaft, the output shaft or the gear rotatably. The rolling bearing includes an inner member, an outer member and a rolling element, and at least any one of the members and element has a carbonitrided layer and a hydrogen content of at most 0.5 ppm.

In the still another support structure in a transmission according to the present invention, embrittlement of steel attributed to hydrogen can be alleviated. If steel has a hydrogen content exceeding 0.5 ppm the steel has reduced anti-crack strength. Such a steel is insufficiently suitable for a support structure for a hub experiencing heavy loads. A lower hydrogen content is desirable. However, reduction of the hydrogen content to the one less than 0.3 ppm requires long-term heat treatment, resulting in increase in size of austenite grains and thus deterioration in toughness. Then, a hydrogen content is desirably in a range from 0.3 to 0.5 ppm and more desirably in a range from 0.35 to 0.45 ppm.

In measuring the above hydrogen content, diffusible hydrogen is not measured and only the non-diffusible hydrogen released from the steel at a predetermined temperature or higher is measured. Diffusible hydrogen in a sample of small size is released from the sample to be scattered even at room temperature, and therefore the diffusible hydrogen is not measured. Non-diffusible hydrogen is trapped in any defect in the steel and only released from the sample at a predetermined heating temperature or

higher. Even if only the non-diffusible hydrogen is measured, the hydrogen content considerably varies depending on the method of measurement. The above mentioned range of hydrogen content is determined by thermal conductimetry. In addition, as detailed later, the measurement may be taken by means of a LECO DH-103 hydrogen determinator or like measuring device.

In the support structure in the transmission as above, preferably the rolling bearing is a tapered roller bearing.

In the support structure in the transmission as above, preferably the rolling bearing is a needle roller bearing.

In the support structure in the transmission as above, preferably the rolling bearing is a ball bearing.

The present invention provides a method of manufacturing a support structure having a rolling bearing supporting an input shaft, an output shaft or toothed wheels rotatably in a transmission capable of changing a rotational speed of the output shaft relative to a rotational speed of the input shaft by means of mesh of toothed wheels, the method comprising the step of forming at least one of an inner member, an outer member and a rolling element of the rolling bearing, wherein the step of forming includes the step of carbonitriding steel for a component of the bearing at a temperature higher than an A_1 transformation point and then cooling the steel to a temperature lower than the A_1 transformation point and subsequently reheating the steel to a range of temperature of no less than the A_1 transformation point and less than the temperature applied to carbo-nitride the steel, and quenching the steel.

In the present method of manufacturing a support structure in a transmission, after steel is carbo-nitrided the steel is cooled to a temperature of less than the A_1 transformation point before it is finally quenched. A fine austenite grain size can be obtained and as a result, Charpy impact, fracture toughness, anti-crack strength, rolling contact fatigue life and the like can be improved.

Furthermore for example by cooling to a temperature at which austenite

transforms, austenite grain boundary in carbonitriding can be irrelevant to that in final quenching. Furthermore, the final quenching temperature is lower than the carbonitriding temperature, and thus the amount of un-dissolved cementite in the surface layer, which is influenced by the carbonitriding process, increases as compared with that in the carbonitriding process. As such the ratio of un-dissolved cementite increases while the ratio of austenite decreases at the heating temperature in the final quenching as compared with those ratios in the carbonitriding process. In addition, it is seen from the Fe-C binary phase diagram that, in the range where cementite and austenite coexist, the concentration of carbon in solid solution of the carbon and austenite decreases as the quenching temperature decreases.

When the temperature is increased to the final quenching temperature, austenite grains are made fine since there remain a large amount of un-dissolved cementite that prevent growth of austenite grains. Moreover, the structure transformed from austenite to martensite through quenching has a low carbon concentration, so that the structure has high toughness as compared with the structure quenched from the carbonitriding temperature.

In the present method of manufacturing a support structure in a transmission, preferably the steel is heated to a range of temperature of 790°C to 830°C before it is quenched.

The steel is again heated to a temperature hardly allowing an austenite grain to be grown before the steel is quenched. Fine austenite grain size can thus be achieved.

The present invention provides a tapered roller bearing having an inner ring, an outer ring, and a tapered roller. At least any one of the inner ring, the outer ring, and the tapered roller has a carbonitrided layer and an austenite grain with a grain size number falling within a range exceeding 10.

In the tapered roller bearing according to the present invention, at least any one of the inner ring, the outer ring and the rolling element that provides a small austenite grain size allows significantly increased anti-crack strength, dimensional stability and

rolling contact fatigue life.   With the austenite grain size number of 10 or less, any remarkable improvement of the rolling fatigue life is impossible and thus the grain size number is greater than 10, and preferably 11 or greater.   Although further finer austenite grains are desirable, the grain size number exceeding 13 is usually difficult to achieve.   Note that an austenite grain of the inner ring, the outer ring, and the rolling element of the support structure of the shaft in the transmission does not vary whether it may be in a surface layer portion significantly affected as it is carbo-nitrided or a portion inner than the surface layer portion.   As such, the surface layer portion and the inner portion will be set as positions serving as subjects of the aforementioned grain number range.

The inner and outer rings in this specification may be integrated with a member such as a shaft or a housing, or may be provided separately from such a member.

[Embodiments]

In the following, embodiments of the present invention will be described with reference to the drawings.

Fig. 1 is a schematic cross-sectional view of a configuration of a transmission in accordance with one embodiment of the present invention.   Referring to Fig. 1, this transmission is a constant mesh transmission mainly including rolling bearings 10A to 10F, an input shaft 11, an output shaft 12, a counter shaft 13, gears (toothed wheels) 14a to 14k, and a housing 15.

Input shaft 11 is rotatably supported by housing 15 via rolling bearing 10A. Gear 14a is provided at the outer peripheral portion of this input shaft 11, and gear 14b is provided at the inner peripheral portion thereof.

One side of output shaft 12 is rotatably supported by housing 15 via rolling bearing 10B, while the other side of output shaft 12 is rotatably supported by input shaft 11 via rolling bearing 10C.   This output shaft 12 is provided with gears 14c to 14g. The axial load of these gears 14c to 14g is supported by rolling bearing 10F that is a thrust needle roller bearing supported by housing 15.

Gears 14c and 14d are provided at the outer and inner peripheral portions of a single member, respectively. The member with gears 14c and 14d is rotatably supported by output shaft 12 via rolling bearing 10D. Gear 14e is mounted on output shaft 12 such that it rotates with output shaft 12 and is slidable in the axial direction of output shaft 12.

Gears 14f and 14g are each provided at the outer peripheral portion of a single member. The member with gears 14f and 14g is mounted on output shaft 12 such that it rotates with output shaft 12 and is slidable in the axial direction of output shaft 12. When the member with gears 14f and 14g slides to the left in the figure, gear 14f can mesh with gear 14b. When the member with gears 14f and 14g slides to the right in the figure, gear 14g can mesh with gear 14d.

Counter shaft 13 is secured to housing 15. Counter shaft 13 rotatably supports a gear member having gears 14h to 14k or the like via rolling bearing 10E. Gear 14h is in constant mesh with gear 14a, and gear 14i is in constant mesh with gear 14c. When gear 14e slides to the left in the figure, gear 14j can mesh with gear 14e. When gear 14e slides to the right in the figure, gear 14k can mesh with gear 14e.

In the present embodiment, the support structure for input shaft 11 has rolling bearings 10A and 10C, while the support structure for output shaft 12 has rolling bearings 10B and 10C. Rolling bearings 10A and 10B are deep groove ball bearings, for example. Rolling bearing 10C is a needle roller bearing, for example. The support structure for gears 14c and 14h to 14k has rolling bearings 10D to 10F. Rolling bearings 10D and 10E are needle roller bearings, for example. Rolling bearing 10F is a thrust needle roller bearing.

Fig. 2 is a schematic cross-sectional view of a configuration of a deep groove ball bearing serving as rolling bearings 10A and 10B aforementioned. Referring to Fig. 2, deep groove ball bearings 10A and 10B each have an outer ring 1 (an outer member) secured to housing 15, an inner ring 2 (an inner member) secured to input shaft 11 or output shaft 12, a plurality of balls 3 rolling between outer ring 1 and inner ring 2, and a

cage 4 holding the plurality of balls 3 in place with a constant space therebetween.

Referring back to Fig. 1, the needle roller bearing serving as rolling bearing 10C has a cage and roller configuration in which a plurality of needle rollers 3b are held by a cage. In this configuration, an outer member of rolling bearing 10C is integrated with input shaft 11, while an inner member thereof is integrated with output shaft 12.

The needle roller bearings serving as rolling bearings 10D and 10E each have a cage and roller configuration in which a plurality of needle rollers 3b are held by a cage. In this configuration, outer members of the rolling bearings are integrated with gears 14c to 14k, while inner members thereof are integrated with output shaft 12 or counter shaft 13. The thrust needle roller bearing serving as rolling bearing 10F has an outer ring 1c (an outer member) secured to counter shaft 13, an inner ring 2c (an inner member) secured to the gear member having gears 14h to 14k, a plurality of needle rollers 3c rolling between outer ring 1c and inner ring 2c, and a cage holding the plurality of needle rollers 3c in place with a constant space therebetween.

At least any one of the outer member (outer ring 1, an outer ring portion of output shaft 12, or gears 14c, 14h to 14k), the inner member (inner ring 2, an inner ring portion of input shaft 11, an inner ring portion of output shaft 12, or an inner ring portion of counter shaft 13), and the rolling element (ball 3 or needle rollers 3b, 3c) includes steel having a carbonitrided layer and has an austenite grain with a grain size number falling within a range exceeding 10.

Furthermore, at least any one of the outer member (outer ring 1, an outer ring portion of output shaft 12, or gears 14c, 14h to 14k), the inner member (inner ring 2, an inner ring portion of input shaft 11, an inner ring portion of output shaft 12, or an inner ring portion of counter shaft 13), and the rolling element (ball 3 or needle rollers 3b, 3c) includes steel having a carbonitrided layer and a fracture stress value of at least 2650 MPa.

Furthermore, at least any one of the outer member (outer ring 1, an outer ring portion of output shaft 12, or gears 14c, 14h to 14k), the inner member (inner ring 2, an

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inner ring portion of input shaft 11, an inner ring portion of output shaft 12, or an inner ring portion of counter shaft 13), and the rolling element (ball 3 or needle rollers 3b, 3c) includes steel having a carbonitrided layer and a hydrogen content in steel that is at most 0.5 ppm.

In the following, a description will be given about a speed-change operation of this transmission.

When gear 14f does not mesh with gear 14b, gear 14g does not mesh with gear 14d, and gear 14e meshes with gear 14j, the driving force of input shaft 11 is transmitted to output shaft 12 via gears 14a, 14h, 14j, and 14e. The transmission in this state is in the first gear, for example.

When gear 14g meshes with gear 14d and gear 14e does not mesh with gear 14j, the driving force of input shaft 11 is transmitted to output shaft 12 via gears 14a, 14h, 14i, 14c, 14d, and 14g. The transmission in this state is in the second gear, for example.

When gear 14f meshes with gear 14b and gear 14e does not mesh with gear 14j, the mesh of gears 14b and 14f couples input shaft 11 directly to output shaft 12 so that the driving force of input shaft 11 is transmitted directly to output shaft 12. The transmission in this state is in the third gear (high gear), for example.

In the following, a description will be given about a heat treatment including a carbonitriding process performed on at least one of components of a bearing, i.e., an inner ring, an outer ring and a rolling element, included in the support structure for a shaft of the transmission according to the present embodiment.

Figs. 3 and 4 show a method of the thermal treatment in the embodiment of the present invention. Fig. 3 shows a heat treatment pattern according to which primary quenching and secondary quenching are carried out, and Fig. 4 shows a heat treatment pattern according to which a material is cooled to a temperature lower than the A_1 transformation point in a quenching process and thereafter heated again to be finally quenched. Both are exemplary embodiments of the present invention.

Referring to Figs. 3 and 4, steel for a bearing's component is first heated to a temperature (e.g. 845°C) higher than the A_1 transformation point. At this temperature, the steel is subjected to carbonitriding process. At the temperature of a treatment T_1, carbon and nitrogen are diffused in a steel matrix such that the carbon can sufficiently be included in the steel. Thereafter, at the temperature of treatment T_1 the steel for the bearing's component is cooled down to a temperature lower than the A_1 transformation point. Thereafter, the steel is again heated to a temperature (e.g. 800°C) of no less than the A_1 transformation point and less than the temperature applied to carbo-nitride the steel. At this temperature, the steel is maintained to be subjected to a treatment T_2. Then, at that temperature, the steel is subjected to oil quenching.

Compared with ordinary or normal quenching (by which carbonitriding is done and immediately thereafter quenching is done once), the above-discussed heat treatment can provide enhanced the crack strength and reduced secular dimensional variation rate while carbonitriding the surface layer. This heat treatment can also produce a microstructure having austenite crystal grains of a grain size which is smaller than the conventional one by one half or more. The component of the bearing subjected to the above-described heat treatment can have a long rolling contact fatigue life, an increased anti-crack strength, and a reduced secular dimensional variation rate.

Fig. 5(a) shows a grain size of austenite of a bearing steel having been heat-treated as shown in Fig. 3. For comparison, Fig. 5(b) shows a grain size of austenite of a bearing steel which has undergone the conventional heat treatment. Figs. 6(a) and 6(b) diagrammatically show the grain sizes of austenite that are shown in Figs. 5(a) and 5(b). In the structures with the crystal grain sizes of austenite, the grain diameter of the conventional austenite is 10 which is a grain size number defined by JIS (Japanese Industrial Standard) while that of the present invention through the heat treatment thereof is 12 and thus fine grains are seen. Further, the average grain diameter in Fig. 5(a) is 5.6 μm measured by the intercept method.

In the following, a description will be given about a modification of the support

structure for the shaft in the transmission of the present embodiment.

In the configuration shown in Fig. 1, rolling bearings 10A and 10B as the support structure for the shaft were deep groove ball bearings. Rolling bearings 10A and 10B, however, may be tapered roller bearings as shown in Fig. 7 or cylindrical roller bearings as shown Fig. 8.

More specifically, at least any one of an outer member (outer ring 1), an inner member (inner ring 2), and a rolling element (roller 3) of each of the tapered roller bearing in Fig. 7 and the cylindrical roller bearing in Fig. 8 includes steel having a carbonitrided layer and has an austenite grain with a grain size number falling within a range exceeding 10.

Furthermore, at least any one of the outer member (outer ring 1), the inner member (inner ring 2), and the rolling element (roller 3) of each above bearing includes steel having a carbonitrided layer and has a fracture stress value of at least 2650 MPa.

Furthermore, at least any one of the outer member (outer ring 1), the inner member (inner ring 2), and the rolling element (roller 3) of each above bearing includes steel having a carbonitrided layer and has a hydrogen content in the steel that is at most 0.5 ppm.

Furthermore, at least any one of the outer member (outer ring 1), the inner member (inner ring 2), and the rolling element (roller 3) of each above bearing is formed by the method as shown in Figs. 3 and 4.

The tapered roller bearing shown in Fig. 7 has, between outer ring 1 and inner ring 2, a plurality of tapered rollers (conical rollers) 3 held by cage 4. This tapered roller bearing is designed such that the raceway surfaces of outer ring 1 and inner ring 2 and the vertex of a cone of roller 3 meet at a point on the center line of the bearing. Therefore, the resultant of forces from the raceway surfaces of outer ring 1 and inner ring 2 presses roller 3 against a large collar of inner ring 2 while guiding and rolling roller 3 along the raceway.

The cylindrical roller bearing shown in Fig. 8 has, between outer ring 1 and inner

ring 2, a plurality of cylindrical rollers 3 held by cage 4.

The needle roller bearing shown in Fig. 9 has, between outer ring 1 and an inner ring portion (not shown), a plurality of needle rollers 3 held by cage 4. Roller 3 generally has a diameter of at most 5mm and a length 3 to 10 times as long as the diameter.

The self-aligning roller bearing shown in Fig. 10 has, between outer ring 1 and inner ring 2, barrel-shaped rollers 3 arranged in two lines and held by cage 4. Such barrel-shaped rollers 3 arranged in two lines give a self-aligning ability capable of handling the inclination of the shaft or the like.

Fig. 11 is a schematic diagram showing the configuration in which the tapered roller bearing shown in Fig. 7 is utilized as a support structure of a shaft in a transmission. Referring to Fig. 11, a shaft 21 on which a plurality of gears 24a to 24d are provided is rotatably supported by housing 15 via tapered roller bearing 10A (or 10B).

Fig. 12 is a schematic diagram showing the configuration in which the self-aligning roller bearing shown in Fig. 10 is utilized as a support structure of a shaft in a transmission. Referring to Fig. 12, a shaft 31 on which a plurality of gears 34a to 34d are provided is rotatably supported by housing 15 via self-aligning roller bearing 10A.

In the configuration shown in Fig. 1, rolling bearing 10C as the support structure for the shaft was a needle roller bearing. Rolling bearing 10C, however, may be the deep groove ball bearing as shown in Fig. 2, the tapered roller bearing as shown in Fig. 7, the cylindrical roller bearing as shown in Fig. 8, the needle roller bearing (the configuration having an outer ring or an inner ring) as shown in Fig. 9, or the self-aligning roller bearing as shown in Fig. 10.

The constant-mesh transmission has mainly been described in the above embodiment. The present invention, however, is not limited to this type of transmission. The present invention is also applicable to other types of transmissions such as a sliding-mesh transmission or a synchro-mesh transmission.

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[Examples]

The present invention in examples will now be described.

Example 1

JIS-SUJ2 (1.0 wt% of C - 0.25 wt% of Si - 0.4 wt% of Mn - 1.5 wt% of Cr) was used for Example 1 of the present invention.   Samples shown in Table 1 were each produced through the procedure described below.

Table 1

Samples	A	B	C	D	E	F	Conventionally carbonitrided product	Normally quenched product
Secondary quenching temp.(°C)	780[1)]	800	815	830	850	870	-	-
Hydrogen content (ppm)	-	0.37	0.40	0.38	0.42	0.40	0.72	0.38
Grain size No. (JIS)	-	12	11.5	11	10	10	10	10
Charpy impact value (J/cm^2)	-	6.65	6.40	6.30	6.20	6.30	5.33	6.70
Fracture stress value (MPa)	-	2840	2780	2650	2650	2700	2330	2770
Rolling contact fatigue life ratio (L_{10})	-	5.4	4.2	3.5	2.9	2.8	3.1	1

1) Not evaluated this time due to insufficient quenching.

Samples A-D: examples of the present invention

Carbonitriding was performed at 850°C held for 150 minutes in an atmosphere of a mixture of RX gas and ammonia gas.   Following the heat treatment pattern shown in Fig. 3, primary quenching was done from a carbonitriding temperature of 850°C, and secondary quenching was subsequently done by heating to a temperature in a temperature range from 780°C to 830°C lower than the carbonitriding temperature. Sample A with a secondary quenching temperature of 780°C was not tested since quenching of sample A was insufficient.

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Samples E and F: examples of the present invention

These samples were carbonitrided through the same procedure as that of samples A-D of the present invention, and then secondary quenched at a temperature from 850°C to 870°C equal to or higher than the carbonitriding temperature of 850°C.

Conventional carbonitrided sample: comparative example

carbonitriding was performed at 850°C held for 150 minutes in an atmosphere of a mixture of RX gas and ammonia gas.　Quenching was successively done from the carbonitriding temperature and no secondary quenching was done.

Normal quenched sample: comparative example

Without carbonitriding, quenching was done by increasing the temperature to 850°C and no secondary quenching was done.

For the samples above, tests were conducted for (1) measuring the amount of hydrogen, (2) measuring crystal grain size, (3) Charpy impact test, (4) measuring fracture stress and (5) rolling fatigue test.　Their results are shown in Table 1.

Their measuring and test methods will now be described.

(1) Measurement of hydrogen amount

The amount of hydrogen was determined by means of a DH-103 hydrogen determinator manufactured by LECO Corporation to analyze the amount of non-diffusible hydrogen in a steel.　The amount of diffusible hydrogen was not measured. Specifications of the LECO DH-103 hydrogen determinator are as follows.

Analysis range: 0.01 - 50.00 ppm

Analysis precision: ±0.1 ppm or ±3 %H (higher one)

Analysis sensitivity: 0.01 ppm

Detection method: thermal conductimetry

Sample weight size: 10 mg - 35 g (max: 12 mm (diameter) × 100 mm (length))

Furnace temperature range: 50°C - 1100°C

Reagent: anhydron ($Mg(ClO_4)_2$), Ascarite (NaOH)

Carrier gas: nitrogen gas, dosing gas (hydrogen gas)

(Both gases have a purity of at least 99.99 % and a pressure of 40 PSI (2.8 kgf/cm^2).)

The procedure of the analysis is roughly described here. A sample was taken by a dedicated sampler and the sample together with the sampler was put into the hydrogen determiner. Diffusible hydrogen therein was directed by the nitrogen carrier gas to a thermal conductimetry detector. The diffusible hydrogen was not measured in this example. Then, the sample was taken out of the sampler to be heated in a resistance heater and non-diffusible hydrogen was directed by the nitrogen carrier gas to the thermal conductimetry detector. The thermal conductivity was measured by the thermal conductimetry detector to determine the amount of non-diffusible hydrogen.

(2) Measurement of crystal grain size

The crystal grain size was measured according to the method of testing the crystal grain size of austenite in a steel defined by JIS G 0551.

(3) Charpy impact test

A Charpy impact test was conducted according to the Charpy impact test method for a metal material defined by JIS Z 2242. A test piece used here was a U-notch test piece (JIS No. 3 test piece) defined by JIS Z 2202. Note that a Charpy impact value is a value of absorption energy E, as described below, that is divided by cross section (0.8 cm^2).

Absorption energy E = WgR (cos β − cosα)

Hammer weight W = 25.438 kg

Gravitational acceleration g = 9.80665 m/sec^2

Distance R from center of axis of rotation of hammer to center of gravity = 0.6569 m

Hammer lifted by angle α = 146°

Hammer moved upward and downward by angle β

(4) Measurement of fracture stress

Fig. 13 shows a test piece utilized for the measurement of fracture stress.

Amsler universal testing machine was employed. A load was exerted in direction P in the figure and the load when the test piece was fractured was measured. Then, the measured load which was a fracture load was converted into a stress by the following stress calculation formula for a curved beam. It is noted that the test piece to be used is not limited to the one shown in Fig. 13 and may be any test piece having a different shape.

Suppose that a fiber stress on the convex surface of the test piece shown in Fig. 13 is σ_1 and a fiber stress on the concave surface is σ_2, then, σ_1 and σ_2 are determined by the following formula (JSME Mechanical Engineer's Handbook, A4-strength of materials, A4-40). Here, N indicates an axial force of a cross section including the axis of the annular test piece, A indicates a cross-sectional area, e_1 indicates an outer radius, e_2 indicates an inner radius, and κ is a section modulus of the curbed beam.

$$\sigma_1 = (N/A) + \{M/(A\rho_o)\} [1 + e_1 / \{\kappa (\rho_o + e_1)\}]$$

$$\sigma_2 = (N/A) + \{M/(A\rho_o)\} [1 - e_2 / \{\kappa (\rho_o - e_2)\}]$$

$$\kappa = - (1/A) \int_A \{\eta / (\rho_o + \eta)\} dA$$

(5) Rolling fatigue test

The rolling fatigue life tester is shown in Fig. 14 in its simplified form, and test conditions for a rolling fatigue life test are shown in Table 2. Referring to Fig. 14, a test piece 221 undergoing the rolling fatigue life test was driven by a driving roll 211 to rotate while being in contact with balls 213. Balls 213 were (3/4)" balls guided by a guiding roll 212 to roll. Balls 213 exerted a high surface pressure on test piece 221 while test piece 221 also exerted a high surface pressure on balls 213.

The results of the above-described measurements and tests will now be described.

(1) Amount of hydrogen

Table 1 shows that the conventional carbonitrided sample without being additionally processed has a considerably large hydrogen amount in the steel that is 0.72 ppm. A reason therefor is considered that ammonia (NH_3) contained in the atmosphere in the carbonitriding process is decomposed and then hydrogen enters the steel. On the

other hand, the hydrogen amount in the steel of samples B-F is reduced to 0.37 - 0.42 ppm and thus almost a half of that of the conventional sample.   This amount of hydrogen in the steel is substantially equal in level to that of the normal quenched sample.

The above-mentioned reduction of the hydrogen amount in the steel can lessen the degree of embrittlement of the steel that is due to hydrogen in the solid solution.   In other words, by the reduction of the hydrogen amount, the Charpy impact value and the fracture stress value of samples B-F of the present invention are remarkably improved.

(2) Crystal grain size

With reference to Table 1, regarding the crystal grain size, samples that are secondary quenched at a temperature lower than the quenching temperature in the carbonitriding process (primary quenching), namely samples B-D have austenite grains which are remarkably made fine, i.e., crystal grain size number is 11-12.   Samples E and F as well as the conventional carbonitrided sample and the normal quenched sample have austenite grains with the crystal grain size number of 10, which means that the crystal grain size of samples E and F is greater than that of samples B-D.

(3) Charpy impact value

Table 1 shows that the Charpy impact value of the conventional carbonitrided sample is 5.33 J/cm^2 while those of samples B-F of the present invention are higher, ranging from 6.20 to 6.65 J/cm^2.   It is also seen from this that a lower secondary quenching temperature leads to a higher Charpy impact value.   The normal quenched sample has a high Charpy impact value of 6.70 J/cm^2.

(4) fracture stress value

The fracture stress corresponds to anti-crack strength.   It is seen from Table 1 that the fracture stress of the conventional carbonitrided sample is 2330 MPa.   On the other hand, the fracture stresses of samples B-F are improved to 2650-2840 MPa.   The normal quenched sample has a fracture stress of 2770 MPa which is in the range of the fracture stress of samples B-F.   It is considered that the reduction in hydrogen content greatly contributes to the improved anti-crack strength of samples B-F as well as the

reduction in size of austenite crystal grains.

(5) Rolling fatigue test

According to Table 1, the normal quenched sample has the shortest rolling fatigue life (L_{10}) due to the absence of a carbonitrided layer in the surface layer. In contrast, the rolling fatigue life of the conventional carbonitrided sample is 3.1 times as long as that of the normal quenched sample. The rolling fatigue life of samples B-D is remarkably improved as compared with the conventional carbonitrided sample. Samples E and F have the rolling fatigue life almost equal to that of the conventional carbonitrided sample.

In summary, the hydrogen content in the steel can be reduced in samples B to F according to the present invention. Thus, the improved fracture stress and Charpy impact values can be achieved in samples B to F. In addition to these fracture stress value and Charpy impact value, the rolling contact fatigue life should desirably be improved. This can be achieved only in samples B to D having even smaller grains with an austenite grain size number of at least approximately 11. Samples B to F correspond to examples in accordance with the present invention, however, the more desirable scope of the present invention is that corresponding to samples B to D that have been subjected to the secondary quenching at a temperature lower than that applied to carbo-nitride the steel and thus has even smaller grains.

Example 2

Example 2 of the present invention is now described.

On the following samples A, B and C, a series of tests was conducted. A material to be heat-treated that was employed commonly to samples A-C was JIS-SUJ2 (1.0 wt% of C - 0.25 wt% of Si - 0.4 wt% of Mn - 1.5 wt% of Cr). Samples A-C were each processed through the following procedure.

Sample A - comparative example: normal quenching only (without carbonitriding)

Sample B - comparative example: quenching directly after carbonitriding

(conventional carbonitriding and quenching)

Carbonitriding was conducted at 845°C held for 150 minutes.   The atmosphere in the carbonitriding process was a mixture of RX gas and ammonia gas.

Sample C - example of the present invention: A bearing material was processed following the heat treatment pattern shown in Fig. 2. carbonitriding was conducted at 845°C held for 150 minutes.   The atmosphere in the carbonitriding process was a mixture of RX gas and ammonia gas.   Final quenching temperature was 800°C.

(1) Rolling fatigue life

Test conditions and the test device for the rolling fatigue life test are as shown in Table 2 and Fig. 7.   Results of the rolling fatigue life test are shown in Table 3.

Table 2

Test piece	$\phi12 \times L22$ cylindrical test piece
Number of tested pieces	10
Counterpart steel ball	3/4" (19.05 mm)
Contact surface pressure	5.88 GPa
Load speed	46240 cpm
Lubricating oil	Turbine VG68 - forced circulation lubrication

Table 3   Test Result

Sample	Life (load count)		Relative L_{10}
	L_{10} ($\times 10^4$ times)	L_{10} ($\times 10^4$ times)	
A	8017	18648	1.0
B	24656	33974	3.1
C	43244	69031	5.4

According to Table 3, carbo-nitrided sample B (comparative example) has a rolling fatigue life (L_{10} life: one out of ten test pieces being damaged) that is 3.1 times as long as that of sample A (comparative example) which undergoes normal quenching only, and thus it is seen that the effect of extending the life is obtained through the carbonitriding process.   In contrast, sample C of the present invention has a longer life which is 1.74 times as long as that of sample B and 5.4 times as long as that of sample A.

It is considered that this improvement is obtained mainly from the fine microstructure.

(2) Charpy impact test

A Charpy impact test was conducted by using a U-notch test piece defined by JIS Z 2242 mentioned above.   Test results are shown in Table 4.

Table 4   Charpy Impact Strength Test

Sample	Charpy impact value (J/cm^2)	Relative impact value
A	6.7	1.0
B	5.3	0.8
C	6.7	1.0

Sample C of an example of the present invention achieved a Charpy impact value equal to that of sample A (comparative example) having undergone only normal quenching and higher than that of carbo-nitrided sample B (comparative example).

(3) Static fracture toughness test

The test piece shown in Fig. 15 was used for the static fracture toughness test. In this test piece, a pre-crack of approximately 1 mm was made, thereafter a static load P by three-point bending was added, and then a fracture load was determined.   Using the following formula, a fracture toughness value (K_{Ic} value) was calculated.   Results of the test are shown in Table 5.

$$K_{Ic} = (PL \sqrt{a}/BW^2) \{5.8 - 9.2 (a/W) + 43.6 (a/W)^2 - 75.3 (a/W)^3 + 77.5 (a/W)^4\}$$

Table 5

Sample	Number tested	K_{Ic} (MPa$\sqrt{}$ m)	Relative K_{Ic}
A	3	16.3	1.0
B	3	16.1	1.0
C	3	18.9	1.2

As the previously introduced crack has a depth greater than the depth of the carbonitrided layer and thus the same results are obtained for samples A and B (comparative examples), while sample C (example of the present invention) achieves a fracture toughness value (K_{Ic} value) approximately 1.2 times as high as those of

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samples A and B (comparative examples).

(4) Static-pressure fracture-strength test (measurement of fracture stress)

A static-pressure fracture-strength test piece as shown in Fig. 13 described above was used. A load was exerted in direction P in the figure to conduct a static-pressure fracture-strength test just as described above. Test results are shown in Table 6.

Table 6   Test Results

Sample	Number tested	Static fracture strength (kgf)	Relative static fracture strength
A	3	4200	1.00
B	3	3500	0.84
C	3	4300	1.03

Carbo-nitrided sample B (comparative example) has a value of a static-pressure fracture-strength slightly smaller than that of sample A (comparative example) having been subjected to normal quenching alone. In contrast, sample C of an example of the present invention has a static-pressure fracture-strength value considerably higher than that of sample B and slightly higher than that of sample A.

(5) Rate of secular dimensional variation

Table 7 shows the rate of secular dimensional variation measured under the conditions of 130°C (holding temperature) and 500 hours (holding time), together with the surface hardness and the amount of retained austenite (at 0.1mm depth from the surface).

Table 7

Sample	Number tested	Surface hardness (HRC)	Retained γ (%)	Rate of dimensional change ($\times 10^{-5}$)	Relative rate of dimensional change[*]
A	3	62.5	9.0	18	1.0
B	3	63.6	28.0	35	1.9
C	3	60.0	11.3	22	1.2

* : smaller is superior

As compared with the rate of dimensional variation of sample B having a large

amount of retained austenite, sample C of an example of the present invention has a lower rate of dimensional variation.

(6) Life test under contaminated lubricant condition

Ball bearing 6206 was used to evaluate the rolling fatigue life under a contaminated lubricant condition having a predetermined amount of normal contaminants mixed therein. Test conditions are shown in Table 8 and test results are shown in Table 9.

Table 8

Load	Fr = 6.86 kN
Contact surface pressure	Pmax = 3.2 Gpa
Rate of rotation	2000 rpm
Lubricant	Turbine 56 - oil bath lubrication
Amount of contaminant	0.4g/1000cc
Contaminant	Grain size: 100-180 μ m, hardness: Hv800

Table 9

Sample	L_{10} life (h)	Relative L_{10}
A	20.0	1.0
B	50.2	2.5
C	74.0	3.7

Sample B (comparative example) having undergone carbonitriding has a lifetime which is approximately 2.5 times as long as that of sample A, and sample C of the present invention has a lifetime which is approximately 3.7 times as long as that of sample A. While sample C of the present invention has a smaller amount of retained austenite than that of sample B of the comparative example, sample C has a long lifetime because of influences of entering nitrogen and the fine microstructure.

It is accordingly seen from the above-discussed results that, sample C of the present invention, namely a bearing component serving as a support structure in a transmission produced by the heat treatment method of the present invention can simultaneously achieve three goals: extension of the rolling fatigue life that has been

difficult to achieve by the conventional carbonitriding, improvement in crack strength and reduction of the rate of secular dimensional variation.

Note that in this specification the austenite grains refer to crystal grains of austenite which is phase-transformed during the heating process, and the traces of grains remain after the austenite is transformed into martensite through cooling.

Although the present invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of the present invention being limited only by the terms of the appended claims. For example, the needle roller bearing may be a full type roller bearing or a shell type needle roller bearing.

[Effects of the Invention]

In the support structure of a transmission, the method of manufacturing the same and the tapered roller bearing according to the present invention, a carbonitrided layer is formed and in addition, a superior fracture stress value not heretofore achieved can be obtained. Therefore, anti-crack strength or the like can be improved in the present invention. Additionally, the support structure can be downsized.

[Brief Description of the Drawings]

Fig. 1 is a schematic cross-sectional view of a configuration of a transmission in accordance with one embodiment of the present invention.

Fig. 2 is a schematic cross-sectional view of the configuration of a deep groove ball bearing serving as rolling bearings 10A and 10B shown in Fig. 1.

Fig. 3 is a diagram for illustrating a method of a thermal treatment in an embodiment of the present invention.

Fig. 4 is a diagram for illustrating an exemplary variation of the method of the thermal treatment in the embodiment of the present invention.

Fig. 5(a) shows a microstructure, more specifically, austenite grain of a bearing according to the present invention, and Fig. 5(b) shows a microstructure, more specifically, austenite grain of a bearing in the background art.

Fig. 6(a) is a drawing of the austenite grain boundary shown in Fig. 5(a), and Fig. 6(b) is a drawing of the austenite grain boundary shown in Fig. 5(b).

Fig. 7 is a schematic cross-sectional view of the configuration of a tapered roller bearing.

Fig. 8 is a schematic cross-sectional view of the configuration of a cylindrical roller bearing.

Fig. 9 is a schematic cross-sectional view of the configuration of a needle roller bearing.

Fig. 10 is a schematic cross-sectional view of the configuration of a self-aligning roller bearing.

Fig. 11 is a schematic diagram showing the configuration in which the tapered roller bearing shown in Fig. 7 is utilized as a support structure of a shaft in a transmission.

Fig. 12 is a schematic diagram showing the configuration in which the self-aligning roller bearing shown in Fig. 10 is utilized as a support structure of a shaft in a transmission.

Fig. 13 shows a sample used in a static pressure fracture strength test (to measure fracture stress).

Fig. 14(a) is a schematic front view of a rolling contact fatigue life tester, and Fig. 14(b) is a schematic side view of the rolling contact fatigue life tester.

Fig. 15 shows a sample used in a static fracture toughness test.

[Description of the Reference Characters]

1, 1c: outer ring; 2, 2c: inner ring; 3, 3b, 3c: rolling element; 4: cage; 10A-10F: rolling bearing; 11: input shaft; 12: output shaft; 13: counter shaft; 14a-14k, 24a-24d, 34a-34d: gear, 15: housing; 21, 31: shaft; 211: driving roll; 212: guiding roll; 213: (3/4)" ball; 221: test piece undergoing a rolling fatigue life test; T_1: carbonitriding temperature; T_2: quenching and heating temperature

【書類名】　　　　図面
DOCUMENT NAME　　Drawings
【図１】

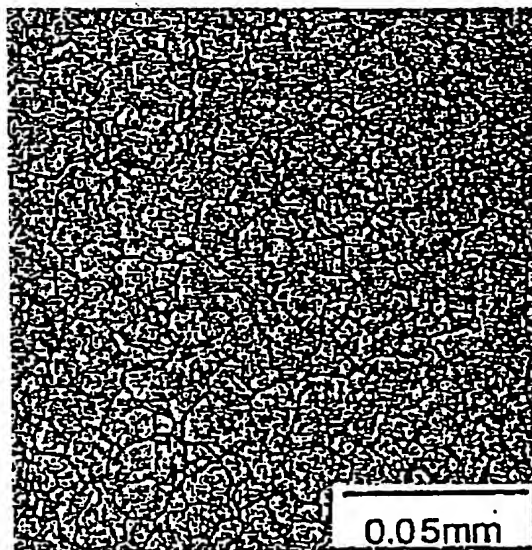Fig. 1
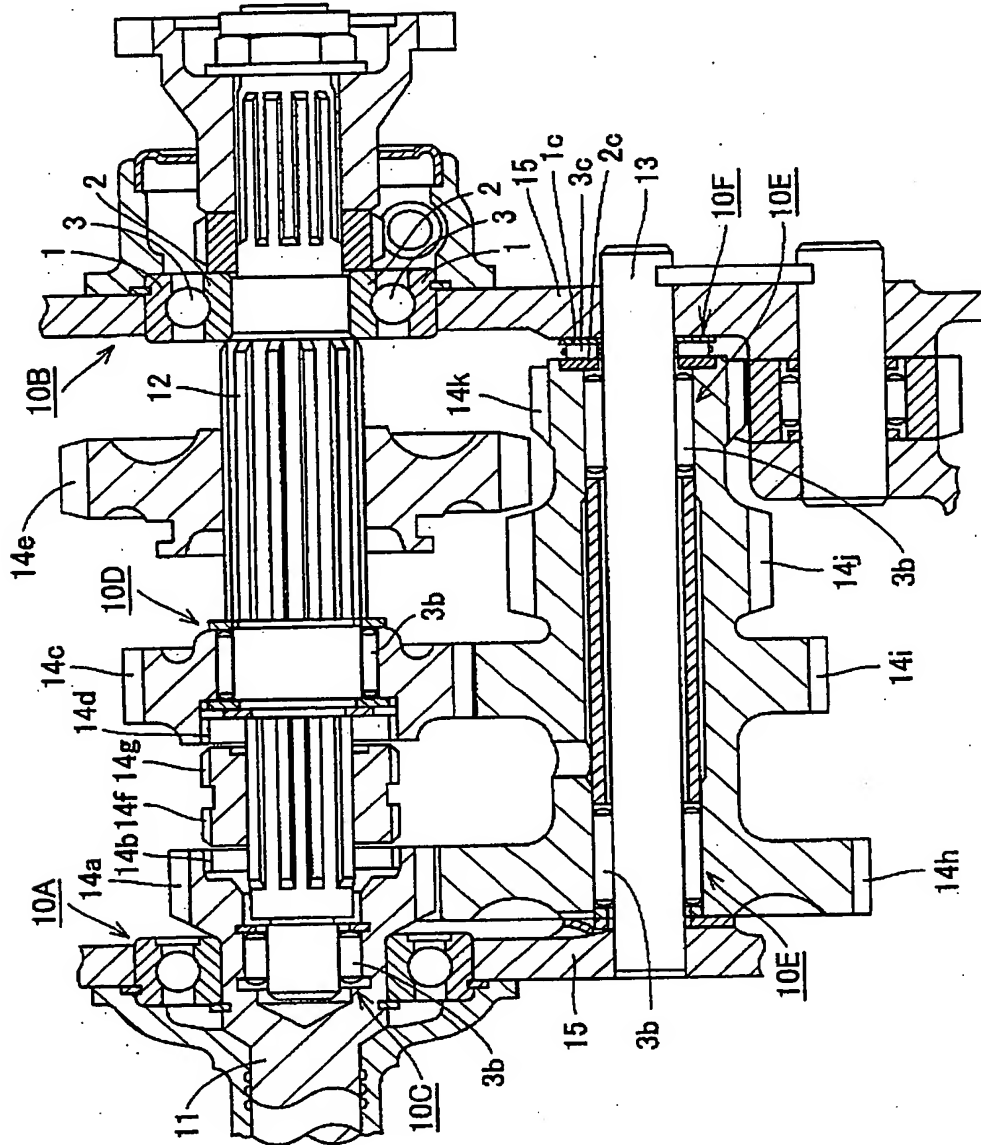
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Fig. 2
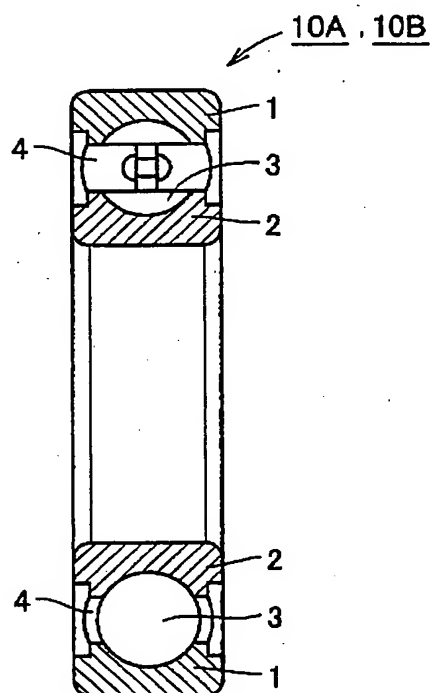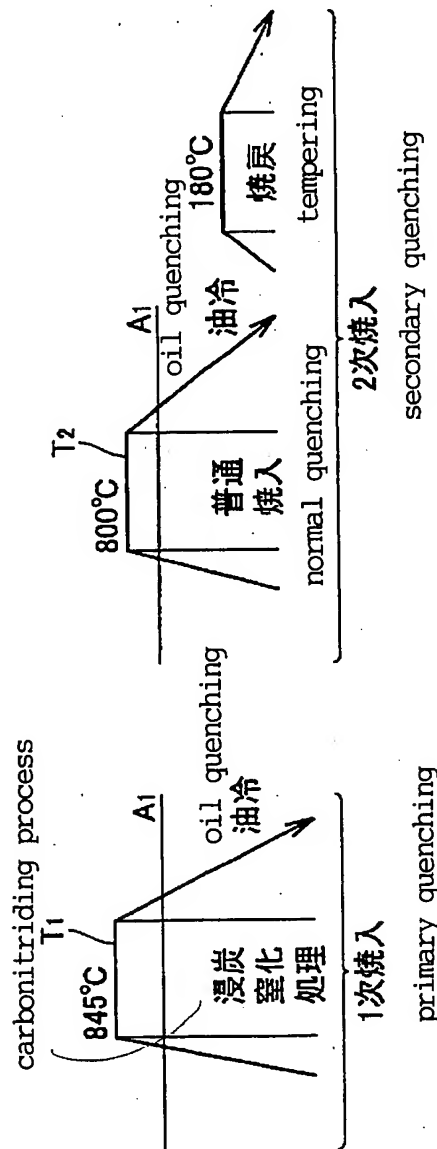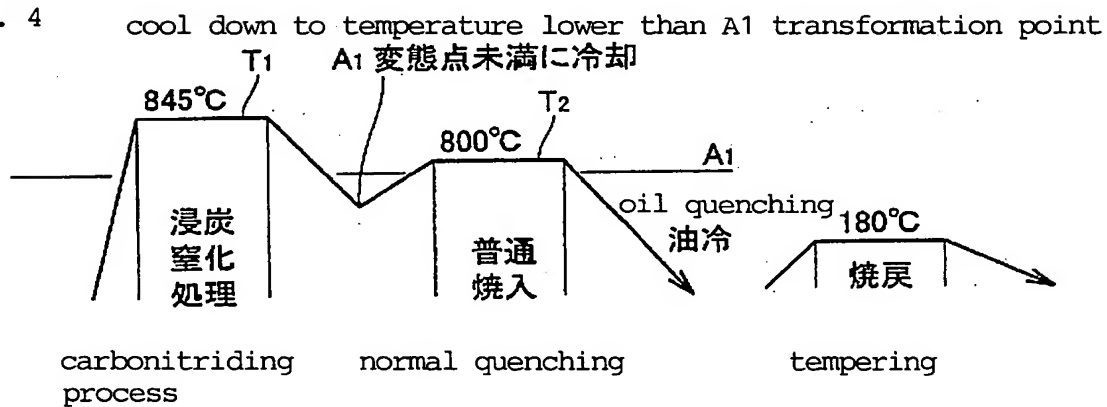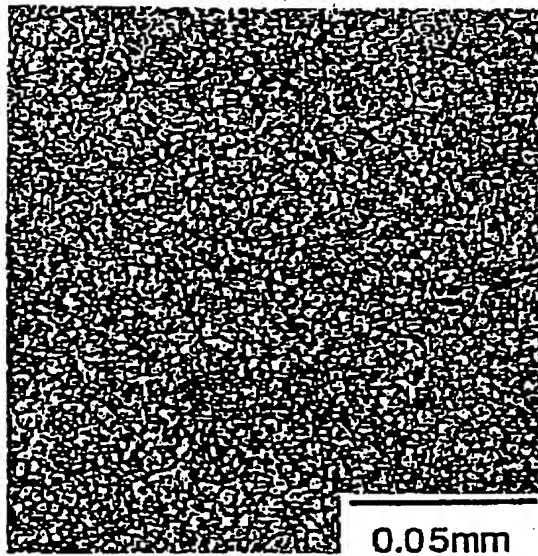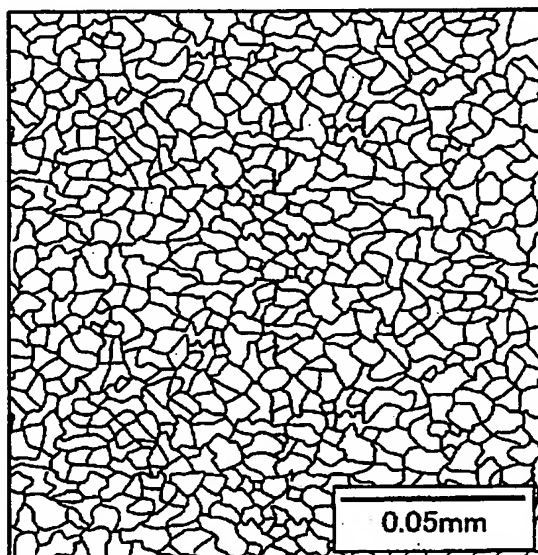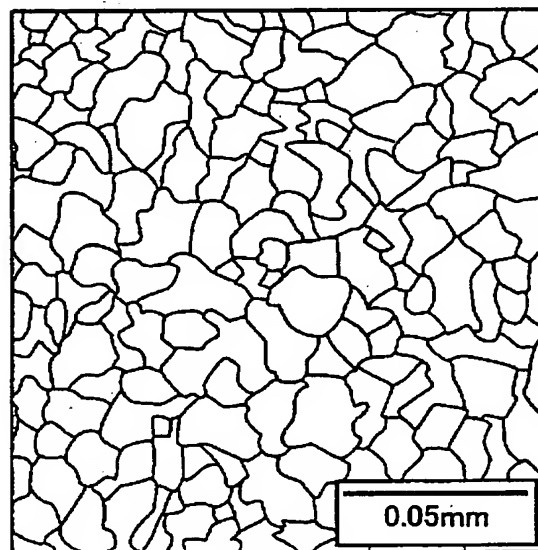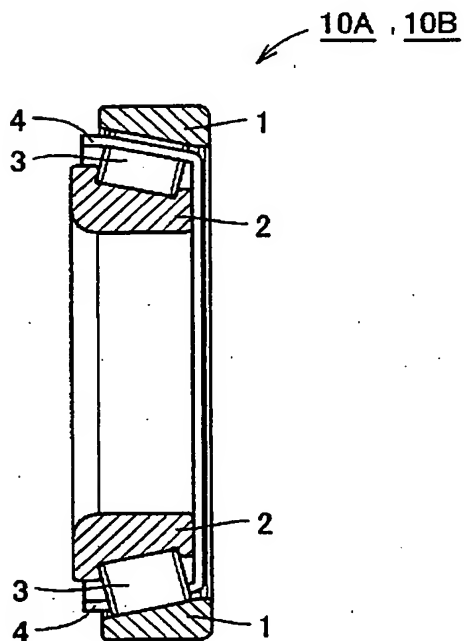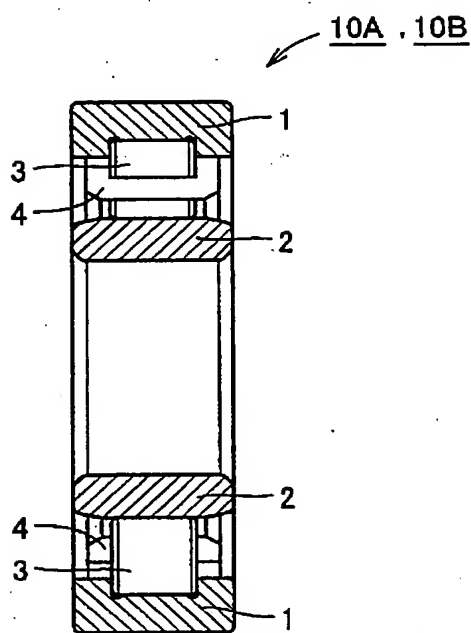
10A , 10B

【図３】
Fig. 3

【図４】
Fig. 4

cool down to temperature lower than A1 transformation point
A1 変態点未満に冷却

845℃　T1
800℃　T2
A1
180℃
oil quenching
油冷

浸炭
窒化
処理

普通
焼入

焼戻

carbonitriding
process

normal quenching

tempering

【図５】

Fig. 5

(a)

0.05mm

(b)

0.05mm

【図６】

Fig. 6

(a)

0.05mm

(b)

0.05mm

【図７】
Fig. 7

【図８】
Fig. 8

【図９】
Fig. 9

【図１０】
Fig. 10

【図１１】
Fig. 11

15
10B
24d
21
24c
24b
24a
15
10A

【図１２】

Fig. 12

【図１３】

Fig. 13
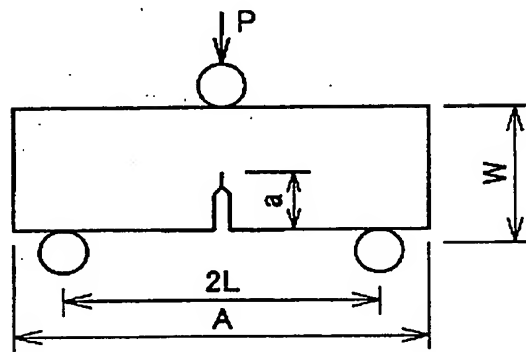
【図１４】
Fig. 14

(a)　　　　　　　　(b)

【図１５】
Fig. 15
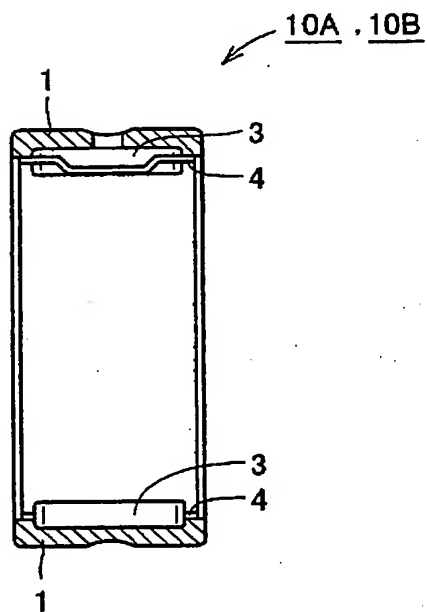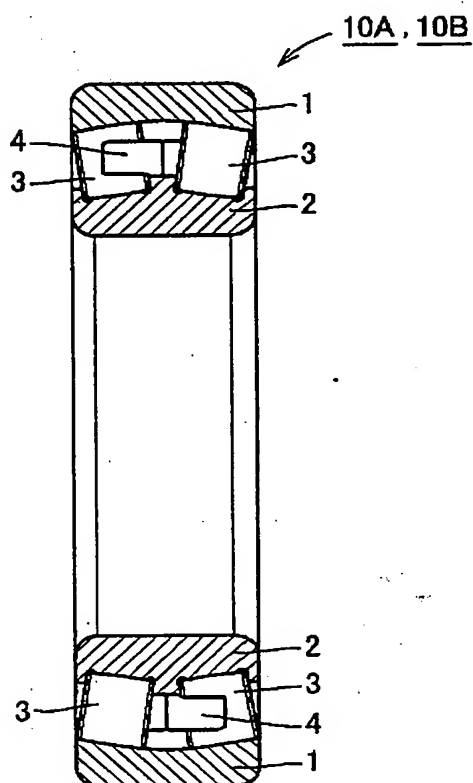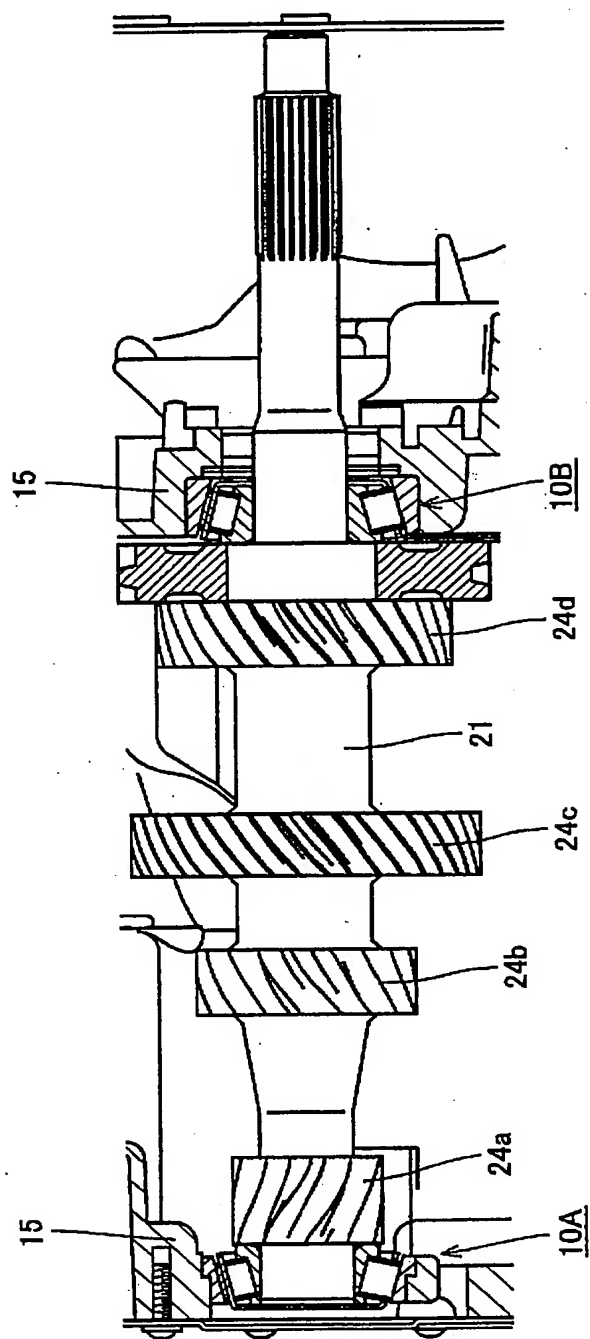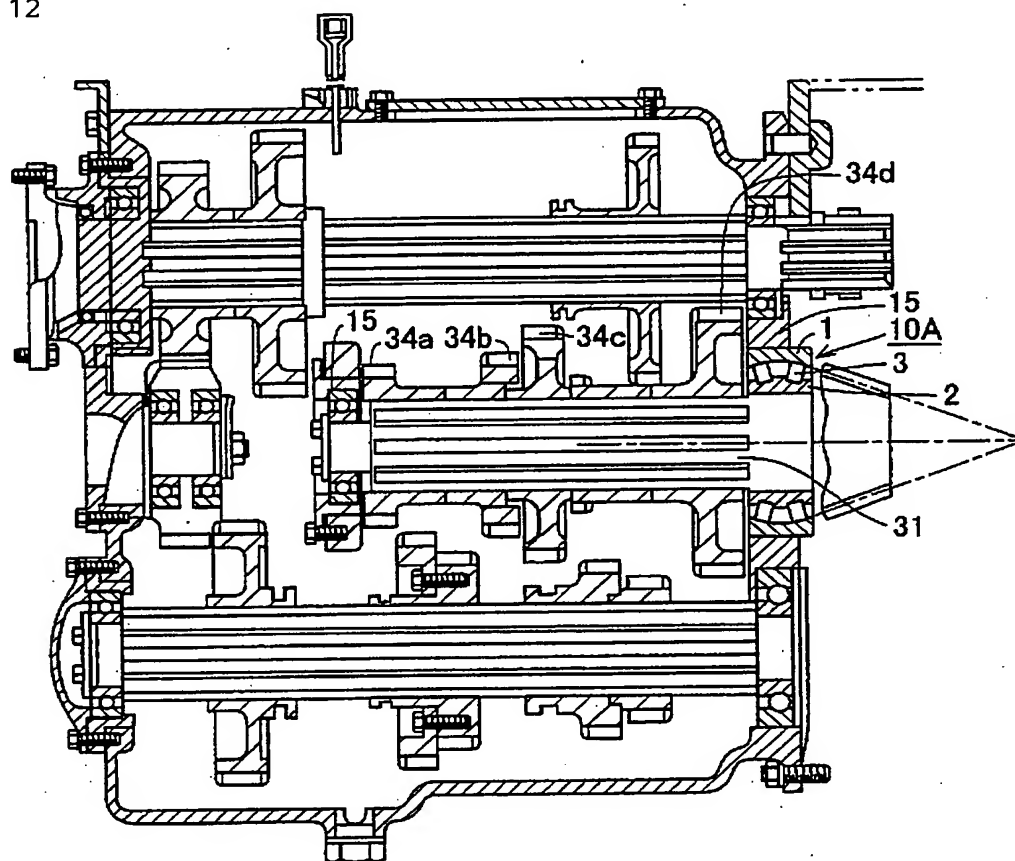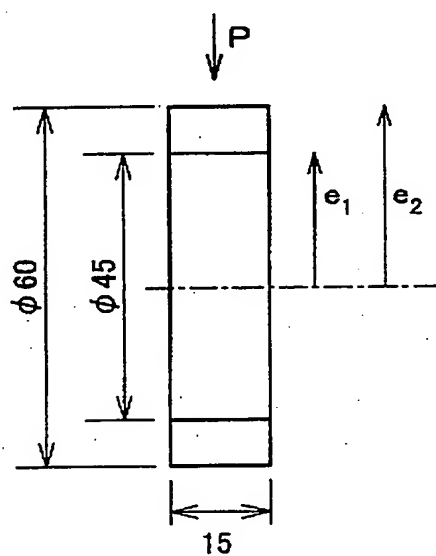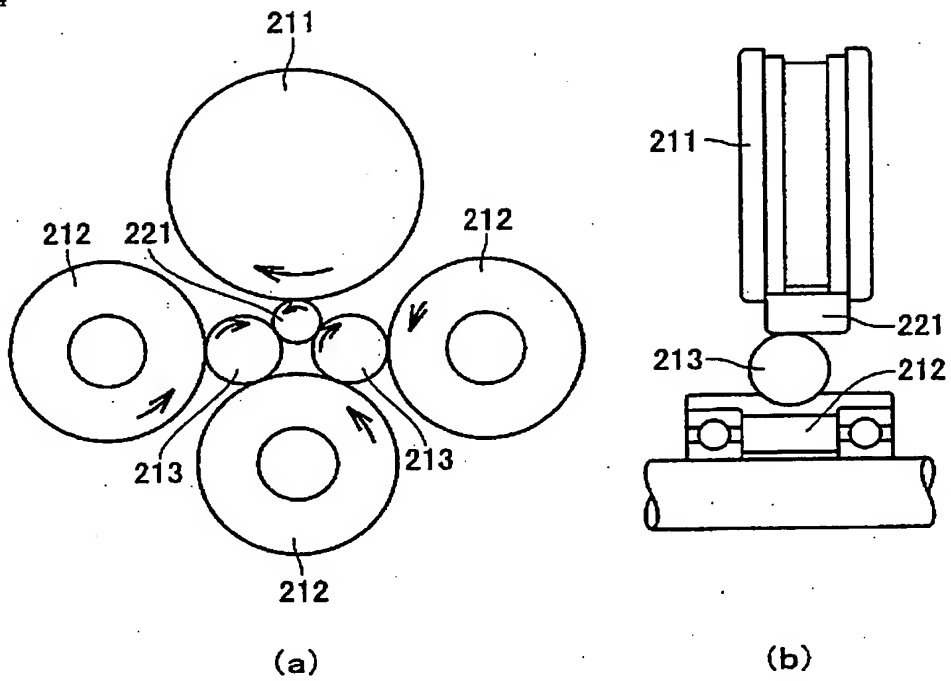
[Document Name]   Abstract

[Abstract]

[Subject]   There is provided a support structure in a transmission that has an increased anti-crack strength, enhanced dimensional stability, and a long rolling contact fatigue life. A method of manufacturing such support structure and a tapered roller bearing are also provided.

[Solving Means]   The present invention provides a support structure in a transmission that has a rolling bearing supporting an input shaft 11, an output shaft 12 or gears 14c, 14h-14k rotatably, wherein the rolling bearing includes an inner member, an outer member and a rolling element, and at least any one of the members and element has a carbonitrided layer and an austenite grain with a grain size number falling within a range exceeding 10.

[Selected Drawing]   Fig. 1